A Few Caveats on Carbon Dioxide Monitoring

by Andrew Persily

I recently read the commentary in your Spring 1994 issue titled "The Value of Monitoring Indoor Carbon Dioxide Levels and IAQ" by Jacob Y. Wong, and I am concerned because his article presents a distorted view of the use of indoor CO_2 monitoring. While techniques exist to relate indoor CO_2 concentrations to building ventilation and indoor air quality, they are not as simple as Dr. Wong suggests. Some of these techniques can yield reliable results when used correctly, while others can result in serious errors. Using any of these approaches requires that one understands the technique and that the following factors are considered:

- The outdoor CO_2 concentration
- The number of people in the building and the rate at which they generate CO_2
- Variations in the number of occupants within the building and over time
- Variations in the CO_2 concentration within the building
- The measurement uncertainty of the CO_2 monitor being used
- Ventilation system operation prior to and during the measurements
- Indoor sources of CO_2 other than the occupants

Correct and incorrect uses of carbon dioxide are discussed in more detail in the articles cited at the end of this article.

While CO_2 measurement can be a useful tool for studying building ventilation and indoor air quality, Dr. Wong's article contains several misconceptions. First, the article states that indoor CO_2 concentrations above 1,000 ppm are associated with increased drowsiness and general discomfort. While such a correlation may eventually be proven, published peer-reviewed data are not available to support this statement. However, even if CO_2 levels above 1,000 ppm are some day shown to correlate with such occupant reactions, it is unlikely that the carbon dioxide is causing these symptoms.

Health effects from CO_2 are generally recognized not to occur until concentrations exceed about 5,000 ppm. Symptoms at lower CO_2 concentrations are presumably due to the concentrations of other airborne contaminants that become elevated when outdoor air ventilation rates are reduced.

The elevated CO_2 levels are simply an indicator of this reduced ventilation. The 1,000 ppm guideline for CO_2 in ASHRAE Standard 62-1989 is based on its association with human body odor and not with any health or comfort effects of the CO_2 itself.

My second problem with the article concerns the issue of whether ventilation rates can be derived from indoor CO_2 levels. While Dr. Wong states unequivocally that they can, this statement is misleading. When carbon dioxide is used to determine ventilation rates, it is being used as a tracer gas. Several tracer gas techniques exist (see ASTM Standard E741-93), and the use of these techniques requires that several conditions exist in the building being measured. The specific requirements depend on the technique being used but generally include a constant outdoor ventilation rate, a constant outdoor tracer gas concentration, and a uniform tracer gas concentration in the building.

Whether CO_2 can be used to measure ventilation in a given building depends on the presence of these and other conditions at the time of the measurement. Depending on the circumstances, measurements of indoor CO_2 concentrations may provide reliable estimates of building ventilation rates or they may yield incorrect results. It is up to the user to understand the measurement techniques, the assumptions on which they are based, and the limits of their use.

Dr. Wong's commentary goes on to question some of the assumptions that are critical to the use of CO_2 for determining ventilation rates, in particular the requirements for "steady-state" conditions and good mixing. I will address the issue of steady-state first. The most common approach to determining ventilation rates from CO_2 concentrations is a simplified ver-

IAQ Journal, Vol. 4, No. 1, pp. 22-25, Summer 1994

sion of the constant injection tracer gas technique.

This approach proceeds as follows: tracer gas is injected into the building at a constant and known rate, i.e., a constant number of occupants are exhaling CO_2 at a known rate; the outdoor air ventilation rate of the building and the outdoor CO_2 concentration are constant; the indoor CO_2 concentration is uniform throughout the building; the indoor CO_2 concentration increases over time above the outdoor concentration; and, enough time has passed that the difference between the indoor and outdoor CO_2 concentrations is at a constant value, i.e., steady-state or equilibrium conditions have been achieved. Given these conditions, the indoor CO_2 concentration is related to the outdoor air ventilation rate per person Q by equation 1 below.

The CO_2 generation rate is roughly 5.3×10^{-6} m3/s (0.011 cfm) per person for a sedentary office worker, but can be very different for occupants engaged in other levels of activity. It is critical to note that the indoor CO_2 concentration must be at steady-state. If the indoor CO_2 concentration is not at steady-state, then this equation is incorrect. The time required to achieve steady-state depends only on the outdoor air change rate of the building in units of air changes per hour (ach). At 0.25 ach (corresponding to 3 L/s, or 6 cfm, per person, and not uncommon in office buildings under minimum outdoor air intake), it takes 12 hours of constant occupancy for the indoor concentration to reach 95% of its steady-state value. At 0.75 ach (corresponding to 10 L/s, or 20 cfm, per person, the minimum recommendation for office space in ASHRAE Standard 62-1989 and more typical of office building ventilation rates), it takes 4 hours for the indoor CO_2 concentration to reach 95% of its steady-state value.

At high air change rates, well above 1 ach, steady-state is reached in three hours or less. In many office buildings, the occupancy is not constant for a long enough period of time to achieve a steady-state CO_2 concentration. If this equation is applied before the indoor CO_2 concentration is at steady-state, then the ventilation rate per person will be overestimated by as much as 100%. In buildings with high air change rates and long periods of constant occupancy, equation one below can be used with more confidence.

Dr. Wong tries to dismiss the steady-state issue by pointing out the fact that we use thermostats to control temperature and that no one requires that the indoor air temperature be at steady-state to do so. The use of indoor CO_2 concentrations to control ventilation and to measure ventilation rates are two very different issues. Of course thermostats can be used to control heating or cooling equipment without steady-state temperature conditions, but that is very different from using a single air temperature measurement to determine the heat loss (or gain) of a building. Such an incorrect use of air temperature is the equivalent of using non-steady state CO_2 concentrations to measure ventilation.

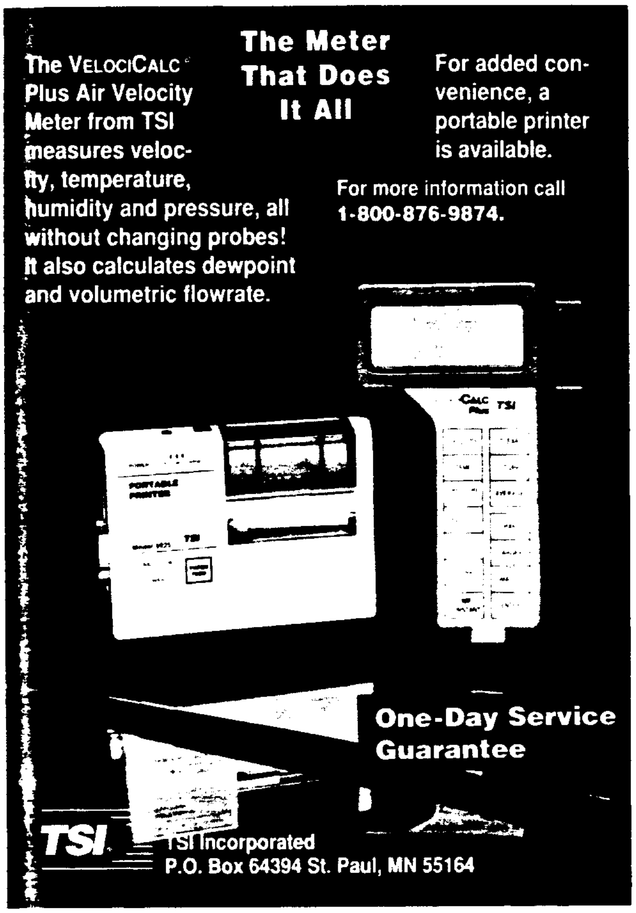
Dr. Wong's commentary goes on to discuss the issue of mixing, but unfortunately it confuses the reader by discussing mixing in conjunction with the unrelated issue of steady-state. A building is "well mixed" if the CO_2 concentration in the building can be characterized by a single concentration measurement. In many situations, the indoor concentration is so variable within a building that it is incorrect to use a single concentration value.

The discussion in the commentary of diffusion driving forces and concentration gradients distracts the reader from the real issue. If the CO_2 concentration in a building is sufficiently uniform that it can be characterized by a single concentration value, then one has overcome a major hurdle in the use of CO_2 as a tracer gas. The steady-state equation presented earlier assumes that the CO_2 concentration in the building can be represented by a single value.

If the CO_2 concentration varies significantly in the space, then one must use much more

$$\text{Vent. rate per person} = \frac{CO_2 \text{ generation rate per person}}{(\text{Indoor } CO_2 \text{ con.} - \text{Outdoor } CO_2 \text{ con.})}$$

Equation 1. Ventilation rate per person expressed as a function of CO_2 generation and indoor and outdoor CO_2 concentrations.



complicated tracer gas techniques. Variations in occupancy and outdoor air delivery within a building can easily lead to significant variations in indoor CO_2 concentrations. Dr. Wong's commentary ends by pointing out that the answer to making ventilation rate measurements with CO_2 is to have a "well-mixed condition." Good mixing by itself does not get one around the issue of whether or not steady-state conditions exist in the building. While good mixing, or a uniform concentration, is necessary for the use of simple CO_2 measurement approaches, the existence of good mixing depends on the building being tested and is not under the control of the person doing the test.

While I have several strong disagreements with Dr. Wong's commentary, your readers should understand that CO_2 can be a useful tool for assessing building ventilation and indoor air quality as long as one understands the techniques they are using and uses them correctly.

On the other hand, the potential for the abuse of CO_2 measurement is very real and must be avoided. One area of agreement between Dr. Wong and me concerns the danger of self-proclaimed experts in ventilation and other factors related to indoor air quality. In the rapidly developing area of indoor air quality, we must all be vigilant of self-proclaimed experts, easy answers and quick fixes, as too often they are shown to be much less than they appear at first glance.

References

Persily, A.K. 1994. Manual for Ventilation Assessment in Mechanically Ventilated Commercial Buildings. NISTIR 5329. National Institute of Standards and Technology, Gaithersburg, MD.

Persily, A.K. 1993. "Ventilation, Carbon Dioxide and ASHRAE Standard 62-1989." ASHRAE Journal, July 1993.

Dols, W.S, and Persily, A.K. 1992. "A Study of Ventilation Measurement in an Office Building." NISTIR 4905. National Institute of Standards and Technology, Gaithersburg, MD.

Persily, A.K., and Dols, W.S. 1990. "The Relation of CO_2 Concentration to Office Building Ventilation." Air Change Rate and Airtightness in Buildings, ASTM STP 1067. M.H. Sherman, Ed. American Society for Testing and Materials, Philadelphia, PA.

Andrew Persily is Group Leader, Indoor Air Quality and Ventilation, Building Environment Division, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland 20899. IAQ